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Feasibility of rice-crab *(Scylla olivacea)* co-cultures in the south-west coastal *ghers* of Bangladesh

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Abstracts. To assess the production performance in terms of growth, survival and intactness of mud crab in co-culture with rice plants an experiment was conducted for a period of 120 days in the *ghers* of two villages under Paikgacha Upazilla, Khulna. The crab juvenile was collected from adjacent Shibsha River and stocked in two experimental *ghers* of 0.004 ha area each without considering male female ratio. The stocking density was 50 per decimal, 75 per decimal, 100 per decimal in T_1, T_2 and T_3 treatments of two experiments, respectively. Fresh chopped tilapia fish was fed to the crab and the requirement of supplied tilapia fish was adjusted periodically in accordance with the growth performance or body weight of crab. Production and physico-chemical parameters were recorded and analyzed according to standard methods. Among these parameters salinity had significant ($p<0.05$) role on survival of mud crab. After 120 days of rearing we obtained average final weight of cultured crab (*Scylla olivacea)* was 154.6±12.19g, 135.46±21.30g and 107.23±14.87g; with the estimated yield of 995.96±193.43 kg/ha, 1179.4±266.68 kg/ha and 1144.22±544.05 kg/ha, survival was 45%, 47% and 42% in T_1, T_2 and T_3 treatments respectively in Bayra village; On the other experimental site in Gopalpur village we obtained average final weight of cultured crab was 169.2±19.20g, 155.22±17.73g and 167.53±18.60g; with the estimated yield of 476.83±160.51 kg/ha, 793.73±361 kg/ha and 1636.19±868.32 kg/ha, survival was 25%, 27% and 22% in T_1, T_2 and T_3 treatments respectively The yield of rice was found 6006±1021 kg/ha, 6026±991 kg/ha, 5995±1005 kg/ha in T_1,T_2,T_3 treatments respectively in the experiment of Bayra village on the other hands in Gopalpur village the yield was 5877±1297 kg/ha, 5743±1350 kg/ ha, 5468±1190 kg/ha in T_1,T_2,T_3 treatments respectively. Results and findings of the present study suggested that yield of rice was not hampered for rice-crab co-culture in *ghers*. According to the experimental results poor salinity level, temperature, water level fluctuation and winter seasons are the potential constraints in the growth, survival and intactness of rice crab co-culture in the coastal *ghers* of Bangladesh.

Keywords: Mud crab, *Scylla olivacea,* Rice, Co-culture

Introduction

Crab is the important saline tolerant shellfish/crustacean species in Bangladesh. Crab aquaculture is more profitable and easy technology and low cost involvement. Greater acceptability especially to the coastal people (Salam *et al.* 2012). Rice fields are an important source of natural food and shelter for fishes, help in better utilization of available land and water resources, and improve rural farmer's income as well (Ahmed *et al.* 2011). After the success of rice-fish culture system, farmers attempted the introduction of crabs in *gher* in northern areas of Bangladesh and obtained better economic growth and farm production (Salam *et al.* 2012). Crabs are rich in micronutrients and vitamins, and thus human nutrition can be greatly improved through crab consumption (Larsen *et al.* 2000, Roos *et al.* 2003). The total area of rice fields is about 10.5 million ha with an additional 2.5 million ha of coastal seasonal rice fields/ghers where water remains for about 4–6 months (BRKB 2021). The carrying capacities of these lands and waters are not fully utilized, but these rice fields exist

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tremendous scope for increasing fish or crab production by integrating aquaculture (Wahab *et al.* 2008). Integrated or co-culture of rice fish or crab production can optimize resource utilization through the complementary use of land and water (Frei and Becker 2005). Integration or co-culture of rice with fish or crab farming improves diversification, intensification, productivity, profitability, and sustainability of limited resource uses (Ahmed *et al.* 2008, Nhan *et al.* 2007). However, rice-crab farming remains marginal in Bangladesh because of socioeconomic, environmental, technological, and institutional constraints (Nabi 2008). The integration or co-culture of mud crab has yet not come to the light in our country. Crab species prefers shelters for their reproduction and growth. Rice fields may be suitable growing ground in coastal areas (Li 1988, Fernando 1993, Little *et al.* 1996). The natural aggregation of fish or crab in rice fields inspired the combination of rice farming with fish to increase productivity (Gurung and Wagle 2005). Many reports suggest that integrated rice-fish or crab farming is ecologically sound because fish improve soil fertility by increasing the availability of nitrogen and phosphorus (Giap *et al.* 2005, Dugan *et al.* 2006). The feeding behavior of crab in rice fields causes aeration of the water. Integrated rice-fish or crab co-culture is also being regarded as an important element of integrated pest management (IPM) in rice crops (Berg 2001 and 2002). Fish control aquatic weeds and algae that act as hosts for pests and compete with rice for nutrients. Moreover, fish eat flies, snails and insects, and can help to control malaria mosquitoes and water-borne diseases (Matteson 2000). Interactions of fish and rice also help lower production costs because insects and pests are consumed by the fish. On the other hand, rice fields provide fish with planktonic, periphytic and benthic food (Mustow 2002). Shading by rice plants also maintains the water temperature favorable to fish during the summer (Kunda *et al.* 2008). The aim of this study is to assess crab co-culture with rice as a competitive alternative to rice monoculture in coastal *ghers*.

Materials and Methods

Gher/Rice field selection and preparation

The culture experiment was conducted in two different locations in Bayra and Gopalpur village of Godaipur union under Paikgacha upazilla at Khulna districts in Bangladesh. The villages situated besides the Shibsha River adjacent to the mangrove forest. Nine experimental *ghers* was selected in each village separately in march 2021.Each *gher* had an area of 0.016 ha with an average water depth of (1$\pm$0.05) m. water holding capacity of *ghers* soil was enough to good. Loamy or clay-loamy soils are suitable for Rice-Crab co-culture. The *ghers* were prepared by drying, removing of unwanted sludge and repairing of embankments in April 2021.Lime was applied at the rate of 250 kg/ha in the *ghers* and left for 7 days. *Ghers* were filled with tidal water from the Shibsha River during high tide and left for 3 days to settle down. *Gher* water was fertilized with 1,250 kg/ha compost cow dung, 37.5kg/ha urea and 25kg/ha TSP in June 2021. These *ghers* were left for 10 days to promote phytoplankton/zooplankton production.

Collection and stocking of wild juvenile

The paddy seedlings were procured from farmers and planted in *gher* in definite intervals in June 2021.Then the wild Crab Juvenile was also procured from crab catchers or fishermen and stocked in July 2021. Crab Juvenile was stocked during evening as they are more sensitive than fin fish fry and cannot tolerate sudden changes in temperature and dissolved oxygen level in water. If they stocked during evening the stocked PL will get more time at night to adopt with the environment. These crabs were collected from the Sibsha River of Khulna districts adjacent to the Sundarbans mangrove forest. The collected crabs are irregular in size (fry, juvenile, sub-adult, adult) and have weight variations (from 2g to 300g).Net devices catches all types/sizes of crab but trap devices catches targated/grade size crab. Among the collected crab's from the Shibsha river; the male female ratio was found more or less 1:1 ratio from the crab catcher's information. Sub adult crab an average weight 20.11$\pm$2.58g (10g-50g) were acclimatized and stocked in 50,75,100 individual per decimal in 0.016 ha area each *ghers* in 1st July, 2021.

Preparation of shading or providing shelter

The *ghers* demarcation line or areas were encircling with nylon net and bamboo fence for preventing escaping of crab. A single ditch was excavated in each *ghers* or treatments of rice field. Ditch was 3 feet water depth and area was 20% of the total *gher* or rice fields. This ditch was served as shelter during sunny days or moulting and makes the harvesting easier. Several canals were dug connecting ditch for free movement of crab. Enough space was left from land boundary so that dyke would not be broken. Ditch was excavated in different position of the plot or rice fields. If someone wishes to stock crab, then it is essential to provide some sort of substances which will serve as shelter for crab. As crab change its shell as growth advances (i.e. molting), it remains very susceptible to attack by other animals during molting period. Substances like coconut branch, palm branch or other tree branches can be supplied in the water for this purpose. Shading is essential during high temperature and excess rainfall to save stocked species from unfavorable condition. Bamboo splits made mat, coconut or palm branch, cultivation of vegetable on rack on dyke can provide shade for the crab.

Feeding and management

Fresh chopped tilapia fish was supplied once in every two days' intervals as Supplementary feed at 3-5% weight of stocked biomass. Feeding regime was adjusted periodically in accordance with the growth performance, total biomass and assuming 100% survival of mud crab. Feeding schedule was once in every 2 days' interval for total culture period (Rodriguez *et al.* 2007). Feed was provided on 5 plastic made feeding trays in every *gher* having an area of 0.01 ha area each. The feed trays were hanged to the bamboo poles and allowed to submerge in the water column. Limed with calcium carbonate was applied at the rate of 65 kg/ha in the *gher* water at 15 days' intervals to kill germs, toxic gases, suspend unwanted particle and supply Ca_2^{++}.In water for helping molting/shell formation.

Monitoring of physico-chemical water parameters

The physico-chemical parameters of pond water were monitored at 9:00 to 10:00AM in every 15 days. Water quality parameters like water temperature (°C), DO (mg/l), CO_2 (mg/l), total alkalinity (mg/l), pH, iron (mg/l), ammonia (mg/l) was monitored using (aqua read multi-meter-2000, Made in England) Salinity (ppt) was measured by photo refractometer (Atago, Japan). Transparency (cm) was measured by using secchi disk and water depth (cm) was measured manually by using meter scale.

Monitoring of growth and estimation of production

Health condition and growth of crab was monitored fortnightly during the full and new moon time. At least 5% of crab was collected by angling device by using lure or bait in the early morning. Length was measured using a centimeter scale and the weight by a portable weighing balance (Tanita, Japan-KD 160). After 120 days of rearing, all crabs were harvested in 30th October,2021 by drying the *ghers* and the following parameters were calculated: Average weight gain (g) = Mean final weight (b) – mean initial weight (a); SGR (%body wt. gain/day) = [(Ln Final wt.- Ln Initial wt.)/ Time interval] × 100); Survival (%) = (Number of fish harvested/Number of fish stocked) × 100; Production/Yield (kg/ha) = [{Number harvested × average final wt. (g)/1000] × Gher area (ha); Food conversion ratio (FCR) = Supplied feed (kg)/harvested total biomass (kg).

Data analysis

Comparison of treatment mean was carried out using one-way analysis of variance (ANOVA), followed by Duncan's Multiple Range Test. Significance at the 5% level ($p < 0.05$) using the SPSS (Statistical Package for Social Science) version-20.

Results

Growth increment of *Scylla olivacea* has been shown in Table I. Initially the growth (length and weight) was optimum then suddenly jumped after one month of culture and slowed down to the moderate state and followed a gradual increment for the entire culture period (Table II).

Table I. Growth, survival and intactness of mud crab in rice fields in rainy season from

Trial: 1	Village: Bayra, Paikgachha, Khulna		
Particulars	T_1	T_2	T_3
Area (ha)	0.004^{a}	0.004^{a}	0.004^{a}
Stocking density (ha)	12350^{a}	18525^{a}	24700^{a}
Mean weight at stocking (g)	24.2 ± 7.31^{a}	21.5 ± 6.93^{a}	18.4 ± 5.92^{a}
Survival rate* (%)	45 ± 9.1^{a}	47 ± 6.3^{b}	42 ± 8.7^{a}
Mean weight at harvest (g)	154.6 ± 12.19^{a}	135.46 ± 21.30^{a}	107.23 ± 14.87^{a}
SGR (%day)	1.85^{a}	1.73^{a}	1.76^{a}
Total biomass produced (kg)	4.03 ± 0.78^{a}	5.51 ± 1.05^{a}	4.63 ± 2.20^{a}

Production rate (kg/ha)	995.96±193.43[a]	1179.4±266.68 [a]	1144.22±544.05[a]
Total feed given (kg)	3.00[a]	4.00[a]	4.00[a]
Feed conversion ratio	0.98±0.50[b]	0.74±0.20[a]	0.97±0.46[a]
Trial: 2	Village: Gopalpur, Paikgachha, Khulna		
Particulars	T_1	T_2	T_3
Area (ha)	0.004 [a]	0.004 [a]	0.004 [a]
Stocking density (ha)	12350 [a]	18525 [a]	24700 [a]
Mean weight at stocking (g)	31.1±8.54[a]	35.5±7.32[a]	38.4±10.55[a]
Survival rate* (%)	25±3.2[a]	27±5.8[b]	22±4.9[a]
Mean weight at harvest (g)	169.2±19.20[a]	155.22±17.73[a]	167.53±18.60[a]
SGR (% day)	1.91[a]	1.85[a]	1.83[a]
Total biomass produced (kg)	1.93±0.64 [a]	3.21±1.46 [a]	6.62±3.51 [a]
Production rate (kg/ha)	476.83±160.51[a]	793.73±361[a]	1636.19±868.32[a]
Total feed given (kg)	2.00[a]	3.00[a]	3.00[a]
Feed conversion ratio	1.01±.47[b]	1.03±0.47[a]	0.52±0.28[a]

*Different superscript letters within the same row indicate a significant difference ($p<0.05$)

In Bayra village after 120 days of culture, average body weight (154.6±12.19g) was highest in T_1 followed by T_2 (135.46±21.30g) and T_3 (107.23±14.87g) with a daily weight increment (SGR) of 1.85%, 1.73% and 1.76% in T_1, T_2 and T_3. Survival was 45%, 47% and 42% in T_1, T_2 and T_3 whereas FCR (food conversion ratio) value was 0.98±0.50, 0.74±0.20, 0.97±0.46. Total production for the pond T_1, T_2 and T_3 was 4.03±0.78 kg, 5.51± 1.05 kg, and 4.63±2.20 kg that ultimately augmented the production of 995.96±193.43 kg/ha, 1358.4±266.68 kg/ha and 1144.22±544.05 kg/ha in T_1, T_2, T_3 treatments respectively (Table I). The experiment was conducted during rainy (temperature fluctuation is extremely high and poor salinity level) period.

In Gopalpur village after 120 days of culture, average body weight (169.2±19.20g) was highest in T_1 followed by T_2 (155.22±17.73g) and T_3 (167.53±18.60g) with a daily weight increment (SGR) of 1.91%, 1.85% and 1.83 % in T_1, T_2 and T_3. Survival was 25%, 27% and 22% in T_1, T_2 and T_3 whereas FCR (food conversion ratio) value was 1.01±.47, 1.03±0.47, 0.52±0.28. Total production for the pond T_1, T_2 and T_3 was 1.93±0.64 kg, 3.21±1.46 kg, and 6.62±3.51 kg that ultimately augmented the production of 476.83±160.51 kg/ha 793.73±361 kg/ha and 1636.19±868.32kg/ha in T_1, T_2, T_3 treatments respectively.(Table I). The experiment was conducted during rainy (temperature fluctuation is extremely high and zero salinity level) period.

Yields of rice have been shown in Table II. According to BBS 2021 (Bangladesh bureau of statistics) the national aman production were 5.56 t/ha in 2020-21. The rice yields of present study were similar to the present data of rice production of Bangladesh. The crab culture was not completely hampered in rice-crab co-culture in the *gher*.

Table II. Rice yields of two different locations in rainy season from

Trial:1	Bayra,Paikgachha, Khulna		
Particulars	T_1	T_2	T_3
Area (ha)	0.004	0.004	.004
Yields (kg/ha)	6006±1021	6026±991	5995±1005
Trial: 2	Gopalpur, Paikgachha, Khulna		
Particulars	T_1	T_2	T_3
Area (ha)	0.004	0.004	.004
Yields (kg/ha)	5877±1297	5743±1350	5468±1190

According to APHA (2005) and Boyd and Fast (1992) recorded all physico-chemical variables like dissolved oxygen, pH, alkalinity, ammonia, nitrite, were found within the acceptable ranges for crustacean aquaculture except the lower salinity, water level and transparency; in T_1, T_2, and T_3 treatments of two experiments respectively during the entire culture period (Table III) The ranges of water quality parameters recorded in the experiment were: salinity: 0-2 ppt; temperature: 16-31° C; pH: 5.5-7.7 and dissolved oxygen: 3.0 - 6 mg/l. These ranges were generally within acceptable levels for mud crab fattening (Cholik and Hanafi 1992).

Table III, Recorded Water quality variables for mud crab aquaculture with rice plants

Experiment: 1	Village: Byra, Paikgachha, Khulna		
Particulars	T_1 (Mean±SD)	T_2 (Mean±SD)	T_3 (Mean±SD)
Temperature (°C)	25.32 ± 5.89^b	26.11 ± 4.93^b	24.00 ± 9.33^b
DO (mg/l)	3.44 ± 0.72^a	3.50 ± 1.50^a	3.71 ± 2.66^a
pH	5.82 ± 0.43^a	6.59 ± 2.30^a	7.04 ± 0.66^a
Salinity(ppt)	1.33 ± 0.42^b	1.17 ± 0.23^b	1.21 ± 0.54^b
Alkalinity (mg/l)	110 ± 10.22^a	103 ± 12.41^a	99 ± 19.68^a
Ammonia (mg/l)	0.03 ± 0.01^a	0.04 ± 0.33^a	0.71 ± 0.11^a
Water level (cm)	15.03 ± 5.03^a	14.4 ± 7.04^a	12.07 ± 6.33^a
Transparency (cm)	14.11 ± 1.42^a	12.43 ± 1.78^a	10.55 ± 1.69^a
Experiment: 2	Village: Gopalpur, Paikgachha, Khulna		
Particulars	T_1 (Mean±SD)	T_2 (Mean±SD)	T_3 (Mean±SD)
Temperature (°C)	23.11 ± 6.50^b	24.33 ± 5.41^b	24.00 ± 8.62^b
DO (mg/l)	4.12 ± 0.49^a	3.60 ± 2.00^a	3.92 ± 1.43^a
pH	6.23 ± 0.11^a	6.60 ± 3.11^a	5.84 ± 0.52^a
Salinity (ppt)	0.0 ± 0.00^b	0.00 ± 0.00^b	0.0 ± 0.00^b
Alkalinity (mg/l)	90 ± 20.00^a	105 ± 17.65^a	79 ± 29.12^a
Ammonia (mg/l)	0.05 ± 0.02^a	0.06 ± 0.23^a	0.51 ± 0.12^a
Water level (cm)	$10.06+6.04^a$	11.3 ± 8.07^a	09.04 ± 7.37^a
Transparency (cm)	09.01 ± 1.53^a	8.55 ± 2.99^a	7.65 ± 1.92^a

*Different superscript letters within the same row indicate a significant difference ($p<0.05$). All the values wear reported mean standard deviation.

Discussions

Traditional or conventional rice cultivation has created various ecological problems such as GHG emission, eutrophication and polluting water resources. But considering environmental safety and sustainable production in co-culture system may be ideal model (Xu *et al.* 2017). Fish cultured in rice fields plays a key role in rice-nutrients interactions to improve crop development (Bashir *et al.* 2019, Feng *et al.* 2021). The co-cultured animal can influence the nutritional contents in surface field water by oxidizing soil surface, decomposition of dead fish, addition of feces, swimming, and recycling the nutrients after grazing on photosynthetic biomass (Bashir *et al.* 2019, Hu *et al.* 2020). Moreover, swimming is the major cause to release fixed nutrients, and dispersion of soil particles making soil more porous that has the ultimate effect on better nutrient uptake by rice (Zheng *et al.* 2014, Teng *et al.* 2016a, Berg and Tam 2018).

Rice-crab co-culture is the culture of rice-crab in a same piece of land. More production can be achieved in rice-crab-fish culture in comparison to the rice monoculture in coastal *gher*. In our experiment of Bayra village crab production found 995.96 $\pm$ 193.43 kg/ha, 1358.4 $\pm$ 266.68 kg/ha and 1144.22 $\pm$ 544.05 kg/ha, in T_1, T_2 and T_3 treatments respectively; and the yield of rice was also found 6006 $\pm$ 1021 kg/ha, 6026 $\pm$ 991 kg/ha, 5995 $\pm$ 1005 kg/ha in T_1, T_2, T_3 treatments respectively. In another experiment of Gopalpur village the obtained yield of crab was 476.83 $\pm$ 160.51 kg/ha, 793.73 $\pm$ 361 kg/ha and 1636.19 $\pm$ 868.32 kg/ha in T_1, T_2, T_3 treatments, respectively and the yield of rice was 5877 $\pm$ 1297 kg/ha, 5743 $\pm$ 1350 kg/ ha, 5468 $\pm$ 1190 kg/ha in T_1, T_2, T_3 treatments, respectively in Gopalpur village. The crab survival rate and production was comparatively higher in Bayra than Gopalpur because of several environmental and water quality parameters acted as catalyst of survival and production of mud crab. But rice production was not hampered in both experimental areas. *Ghers* were fertilized with organic fertilizers (organic manure, molasses) and inorganic fertilizers (Urea, TSP, Ammonium phosphate). Also, liming and water filling are done as a part of *gher* management practices.

Crabs grow by molting its exoskeleton. In winter season crab culture is not profitable at all. The duration of the crab culture period varies and depends on the sized stocked, amount of supplied feeds and market price. (Islam *et al.* 2015). One of the common features of mud crab fattening/hardening or aquaculture in ponds/ghers is selective or progressive harvesting and restocking. Occurring of mortality at/after stocking because of poor quality and handling of crab seeds and lack of knowledge on best management practices hampers production and income in rice-crab co-culture systems in *gher*. Crab fattening/hardening or aquaculture offers comparatively higher returns than other aquaculture practices in coastal *ghers*. Some farmers practice grow-out of crab by stocking small (1-50 g) crab seed in ponds or *ghers* to reach market size. Our results are higher than Rahman *et al.* (2022) findings who was conducted a monoculture crab research for a period of 120 days from July to October 2021 in the farmer's ponds of

Betbunia village under Paikgacha upazilla at Khulna, Bangladesh. After 120 days of rearing, obtained average final weight was 97.8±13.86g, 94.22±9.25g and 117.77±14.34g; with the estimated yield of 371.56 kg/ha, 433.12 kg/ha and 376.56 kg/ha, survival rate was 38%, 46% and 32% in T_1, T_2 and T_3 treatments respectively. The probable or important factor/catalyst is survival of sub-adult crab after stocking for growth and production of mud crab. Survival increases when juvenile faces less stress in transportation or catching in river or temperature and salinity of *gher*. The difference of weight gain was not statistically ($p > 0.05$) significant in three treatments. But production rate of crab was found 1358.4±266.68 kg/ha in T_2 treatments, which was significantly ($p > 0.05$) difference from T_1 and T_3 in Bayra village. In Bangladesh there was no research work on rice crab co-culture but few monoculture or mixculture found. Saha *et al.* (1991) conducted 10-weeks monoculture trial of mud crab in brackishwater earthen pond in three stocking densities 5,000 crablings/ha, 10,000 crablings/ha and 15,000 crablings/ha. In terms of production, survival, growth and carapace width, the author found the best performance from the stocking density 10,000/ha followed by 15,000/ha and 10,000/ha. In terms of production the present study reveals, that having stocking density of 18,525/ ha found highest production which is supported by the finding of Rahman *et al.* (2022), where author showed relation between production and percentage of survival, so positive impact of low stocking density. At the end of the experiment survival of mud crab was found 45%, 47% and 42% in T_1, T_2 and T_3 treatments in Bayra village which are lower than Begum *et al.* (2009) who found survival rate of crab was 93.75±6.25% in cages, 86.12±2.16% in earthen ponds. The lower survival rate in encircled earthen pond could be due to the poor salinity level and cannibalistic nature of mud crab. An adequate supply of feeds and provision of three-dimensional shelters, including PVC pipes, straw-sheafs, leaf fronds, bamboo pieces, unused nets, coconut leaves and mangrove twigs, provided for reducing cannibalism. Cannibalism is a big problem for crab aquaculture. In Vietnamese intensive monoculture of mud crab, the stocking density was 1- 1.5/m^2, achieving 1.5t/ha for each crop. After 4-6 months, the crabs achieved an average weight of 300-450g and fed with trash fish and mollusks. In China a field survey and a field experiment on rice-crab co-culture were combinedly carried out at Panjin City, China. They discovered this agri-aquaculture technique is an environmentally friendly. However, the aim of their study was to explore its knowledge about soil nutrients status and their composition in rice grain. The field survey with 16 fields each for rice-monoculture and rice crab co-culture was conducted without influencing conventional cultural practices. The field experiment was conducted with four treatments: rice-monoculture 3,000 crabs/ha without feed, 6,000 crabs /ha with feed and 12,000 crabs/ha with double feed. Results showed an increase in soil nutrients and improved nutrient accumulation in rice with the rice-crab co-culture system. The results implied that the improvement of rice yield was by the increased nutrient in soil and the higher nutrient translocation capacity from soil to rice under the proper culturing crab density. To decrease negative environmental impacts, Khoshnevisan *et al.* (2021) also conducted a research on rice with crabs co-culture and found promising results. However, there are still serious concerns about the proper implementation of rice co-culture systems. Having considered rice-crab systems, crab stock density and the amount of crab feed, among others, are two important factors which regulate the performance of the system and the associated environmental pollution. Moreover, the attempts were made to explore the underlying correlations between crab stock density and the amount of crab feed as two independent variables and measured parameters such as yield and greenhouse gas emissions. Furthermore, an appropriate optimization model was developed to find the optimal crab density and crab feed in order to minimize the environmental pollution and maximize crab and rice yield as well as net profit.

The overall total production of crabs in all treatments of two experimental areas were found lower than recorded by Bashir *et al.* (2022) which may be due to poor salinity level, cannibalism and adverse weather (unexpected storm with raining, cold shock for sudden temperature fall, continuous water level fluctuation in gher. The fluctuation of salinity and temperature causes stress, mortality (Quinitio *et al.* 2008). According to APHA (2005) and Boyd and Fast (1992) recorded all physico-chemical variables like dissolved oxygen, pH, alkalinity, ammonia, nitrite, iron and transparency; were found within the acceptable ranges for crustacean aquaculture except the lower salinity levels inT_1, T_2, and T_3 treatments respectively during the entire culture period. The ranges of water quality parameters recorded in the experiment were: salinity: 0-4 ppt; temperature: 26-31^{o} C; pH: 7.5-8.7 and dissolved oxygen: 4.0 - 7.9 mg/l. These ranges were generally within acceptable levels except salinity for mud crab fattening.

Rice co-culture system has been adopted about 2000 years ago in Asian countries (Deependra *et al.* 2014) and obtained a key position as a cultural activity in China (Li 1988). While, the RC (rice-crab) co-culture system is again attaining the attentions of farming community in modern decades (Bashir *et al.* 2019). In course of time, this practice became introduced in Indonesia, Vietnam, Thailand, India and many other countries of the world. This system can optimize land use plan with efficient usage of scared land and water resources, also is involved significantly in reduction of fertilizers and pesticides application (Xie *et al.* 2011). In Bangladesh, generally this culture is practiced during aman seasons (Islam *et al.* 2015). Advantages of rice-crab co-culture production of crab as additional crop, Insect or pest that attacks the paddy can be controlled by stocked crab as crab takes those organisms as feed, Fecal or semi-fecal materials discharge from the crab body serve as fertilizer in the rice field as a result fertility of the field increase (Bashir *et al.* 2019). RC co-culture model is suitable for sustainable rice production, and plays a key role in energy by labor utilization, fertilizer use efficiency, and forage input (Xu *et al.* 2019). Ministry of Agriculture of P.R. China has advised the farmers to change their mono-fish culture and RM culture to co-culture system for advanced livelihood of the rural community (Feng *et al.* 2016). Two models for RC system (1) crab juvenile aquaculture (June–October); (2) rearing juvenile Fattening/hardening (March–July), have been considered for ecological benefits, yield, and food web, and feeding habits, also concluded RC system has capacity to improve environmental ecology and farm economy (Xu and Ma 2014).

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